

"Data Analysis Tasks--BATSE"

44 P

FINAL REPORT

Contract NAS8-38609
Delivery Order Number 9

September 30, 1991 - February 27, 1993

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May 1993

N94-12427

Unclass

G3/92 0180066

(NASA-CR-192598) DATA ANALYSIS
TASKS: BATSE Final Report, 30 Sep.
1991 - 27 Feb. 1993 (Alabama
Univ.) 44 p

1. INTRODUCTION

The Burst and Transient Source Experiment (BATSE) is one of four instruments on the Compton Observatory which was launched by the space shuttle Atlantis on April 5, 1991. As of the end of February, 1993, BATSE detected more than 570 cosmic gamma-ray bursts and more than 600 solar flares. Pulsed gamma-rays have been detected from more than a dozen sources and emission from a similar number of sources has been detected by the Earth occultation technique. The daily BATSE operations tasks represent a substantial level of effort and involve a large team which includes MSFC personnel as well as contractors such as UAH. The effort is naturally divided into several areas: data operations, burst operations, occultation operations, and pulsar operations. UAH personnel have been involved to some extent in all of these as well as contributing to various areas of scientific data analysis.

2. MISSION OPERATIONS

Z. Shariff and D. Preece assisted in BATSE data operations on a regular basis. Shariff, T. Koshut, R. Mallozzi, and M. Stollberg performed burst operations regularly. W. Paciesas continued to serve as BATSE Mission Operations Software (MOPS) Development Manager, chairing the Level V Configuration Control Board for the MOPS software. M. Murthy studied the in-orbit performance of the MOPS energy calibration software and investigated effects of systematic variations in the detector backgrounds. He developed software to produce time-integrated, filtered calibration files.

Paciesas headed the BATSE Occultation Analysis team for Mission Operations and helped coordinate the effort to develop enhanced occultation analysis software. The current status of this software was summarized by Ling et al.¹ The standard MOPS occultation analysis software has evolved as our understanding of systematics improves. During normal MOPS, Paciesas² discovered a bright new transient source in the constellation Perseus, designated GRO J0422+32. Paciesas also participated in the discovery of outbursts of the recurrent transient sources 4U 1543-47 (Ref. 3) and GX 339-4 (Ref. 4).

Another aspect of MOPS quick-look science in which Paciesas was involved was the fast determination of accurate locations for

gamma-ray bursts using a combination of the CGRO BATSE and/or COMPTEL locations together with the Interplanetary Network of burst detectors. This will enable sensitive searches for burst counterparts to be performed in other wavelengths much closer to the occurrence time of the burst. The first major success in this regard occurred with the burst of January 31, 1993, for which a location error box of area $\sim 180 \text{ arcmin}^2$ was reported within 3 days.⁵

3. DATA ANALYSIS

G. Pendleton continued his efforts to improve the BATSE detector response matrices using data from solar flares as well as the bright source in the Crab Nebula. He delivered to MSFC the first version of a software package to produce matrices for arbitrary angles of incidence and geocenter direction. Validation of the response matrices using independently-located gamma-ray bursts was also performed.⁶ Stollberg assisted in this effort.

Pendleton, working with Paciesas, Koshut, and Mallozzi, used the response matrices to show evidence for two spectral states in bursts.⁷

Paciesas collaborated with B.C. Rubin (USRA) and others at MSFC, JPL, and UCSD to develop a comprehensive model of the background variations in the BATSE large-area detectors.⁸

Paciesas coordinated BATSE spectral analysis efforts among UAH, MSFC, GSFC, and UCSD. Builds of BSAS were distributed by GSFC in September, 1991, January, 1992, and October, 1992. A major concentration was the search for cyclotron features in burst spectra. No convincing line features have been found so far.^{9,10} However, statistics are not yet good enough to show a disagreement with previous observations by Ginga. Note that the response matrices are crucial in the search for and analysis of cyclotron lines. Paciesas and Pendleton collaborated with others on the BATSE team to study the low-energy response of the Spectroscopy Detectors,¹¹ to search for microsecond flaring in bursts,¹² and to characterize burst continuum spectra and spectral evolution.^{13,14}

In the area of occultation analysis, Paciesas concentrated on analysis efforts which evaluated systematic errors and showed

that good agreement could be obtained for weak, isolated sources¹⁵ but correlated errors remain a problem in crowded regions such as the Galactic center.¹⁶

Paciesas and Pendleton collaborated with B.A. Harmon (MSFC) on occultation observations of black-hole candidates,^{17,18} with C.A. Wilson (MSFC) on analysis of data from GS 0834-430,¹⁹ and with R.B. Wilson (MSFC) on analysis of BATSE data from isolated pulsars.²⁰⁻²² Paciesas collaborated with Rubin on analysis of data from 4U1700-377,²³ with M.H. Finger (CSC) on analysis of data from Cen X-3,²⁴ with B. McNamara (New Mexico St.) on correlated BATSE/optical observations of Sco X-1,²⁵ with C. Kouveliotou (USRA) on analysis of quasi-periodic oscillations from Cyg X-1 and GRO J0422+32,²⁶ and with D. Chakrabarty (CalTech) on analysis of the orbit of OAO 1657-415.²⁷

Stollberg (with Paciesas, Pendleton and others) determined orbit parameters for the transient, pulsating x-ray binary EXO 2030+375.²⁸ He will continue work on this object as part of his Ph. D. dissertation.

In the area of gamma-ray bursts (GRB), Paciesas collaborated with M.S. Briggs (UAH) on isotropy tests applied to the BATSE GRB sky distribution,^{29,30} with Rubin and J. van Paradijs (U. of Amsterdam) on searches for untriggered bursts in BATSE data,^{31,32} with S. Howard (USRA) on searches for GRB counterparts among known objects,³³ with M. Boer and J. Greiner (MPI Garching) on simultaneous searches for x-ray and optical counterparts,^{34,35} with V.E. Kargatis (Rice) on GRB spectral evolution,³⁶ with P.N. Bhat (NAS/NRC) on temporal studies of short GRBs,^{37,38} with J.P. Norris (GSFC) on GRB pulse shape studies,^{39,40} and with Kouveliotou on the recurrent bursts from the Soft Gamma Repeater SGR 1900+14 (Ref. 41-42) and a color-color analysis of burst spectra.⁴³

Pendleton and Paciesas collaborated with C.A. Meegan (MSFC) on the GRB spatial distribution,^{44,45} with J.M. Horack (MSFC) on angular correlation analyses of GRBs,⁴⁶ an investigation of systematic errors in BATSE burst locations,⁴⁷ and a search for weak, long-lived emission from GRBs,⁴⁸ with J. Hakkila (Mankato St.) on GRB model constraints resulting from BATSE observations,⁴⁹ and with J.P. Lestrade (Mississippi St.) on GRB time history structure.⁵⁰

Koshut (with Paciesas, Pendleton, and others) studied GRB spectral variability on short timescales.⁵¹ Mallozzi (with Paciesas and others) studied the systematics of BATSE trigger classification.⁵²

4. OTHER ACTIVITIES

Paciesas served as Co-Chair with G. Fishman (MSFC) of the Organizing Committee for the Gamma-Ray Burst Workshop which was held in the Tom Bevill Center on the UAH campus on October 16-18, 1991. Pendleton served as a member of the Organizing Committee. There were a total of 132 registered participants, of which 29 represented foreign institutions. The program included 10 invited oral presentations, 52 contributed oral presentations, and 29 poster presentations. Paciesas and Fishman co-edited the conference proceedings, which were published by the American Institute of Physics.⁵³

Paciesas presented invited talks on "BATSE observations of X-ray binaries" and "Monitoring AGNs with BATSE" at the Ising Workshop on Joint GRO Studies, Ising/Chiemsee, Germany, during June 22-24, 1992. Paciesas presented contributed papers at the symposium on Recent Advances in High Energy Astronomy, Toulouse, France, during March 17-20, 1992 and the workshop on The Multi-Wavelength Approach to Gamma-Ray Astronomy, Les Diablerets, Switzerland, during February 2-5, 1993. Paciesas, Pendleton, Stollberg, Mallozzi, and Koshut presented contributed papers at the Compton Symposium, St. Louis, MO, during October 15-17, 1992. Paciesas and Stollberg presented contributed papers at the American Astronomical Society meeting, Phoenix, AZ, during January 3-7, 1993.

Paciesas continued to serve as BATSE representative on the Compton Users' Committee, attending meetings in March, 1992, July, 1992, and October, 1992. Paciesas provided BATSE inputs for the Phase 3 Guest Investigator Program Research Announcement⁵⁴ which was issued in December, 1992.

Support for the study of ionospheric disturbances by high-energy astrophysical phenomena was provided as needed.

Pendleton and Paciesas completed what is expected to be the final draft of the paper on balloon-borne observations of SN1987A. The draft was distributed to all co-authors but journal

submission has been delayed pending receipt of co-authors' comments.

Copies of publications involving UAH personnel as principal author are attached.

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ATTACHMENTS

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SPECTRAL VARIABILITY IN GAMMA-RAY BURSTS ON MILLISECOND TIMESCALES

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ABSTRACT

We report on preliminary results of an investigation of spectral variability on millisecond timescales within short duration (≤ 0.5 s) gamma-ray bursts using data obtained with the Burst and Transient Source Experiment onboard the Compton Gamma-Ray Observatory. We use hardness ratios to examine short duration bursts for trends in spectral evolution, as well as to identify any association of spectral evolution with burst intensity. Previous studies of spectral variability within bursts have shown a tendency for hard-to-soft evolution throughout the burst as well as throughout individual pulses.^{1,2} The capability to examine short duration bursts has been limited in previous experiments by the lack of significant source counts on timescales sufficient to resolve the temporal variability characterizing these events.

DATA ANALYSIS

BATSE consists of eight uncollimated Large Area Detectors, each with a frontal area of 2025 cm², spanning an energy range of ~ 20 –1800 keV. Details of BATSE instrumentation can be found elsewhere.^{3,4} Upon satisfaction of a number of trigger criteria, the instrument begins to accumulate various burst data types. Time-Tagged Event (TTE) data are chosen for this study. TTE data consist of individual photon arrival times in four discriminator energy channels, with a time resolution of 2 μ s. The TTE onboard memory is organized as a continuously running ring-buffer. Once a burst trigger occurs, the accumulation of TTE data halts after three-fourths of the memory fills. The remaining memory contains data immediately prior to the trigger. Therefore, the interval of TTE data coverage depends upon the intensity of the triggered event. Accumulation of TTE data is not restarted until a burst data readout is completed (~ 5600 seconds after trigger time); therefore, TTE data are not available for bursts that trigger during a readout. For these cases we use a combination of Preburst (PREB) and Discriminator Science (DISCSC) data, which consist of count rates in four discriminator channels, with a time resolution of 64 ms. PREB data are available for all eight detectors, and cover the 2 seconds immediately prior to the trigger time. DISCSC data are summed onboard over the triggered detectors, and span the 240 seconds following the trigger time.

The TTE and PREB data are summed over the triggered detectors to improve the statistical significance of our results. The TTE data are rebinned to obtain a time resolution between 1 and 32 ms. There is no need to rebin the

PREB or DISCSC data into a coarser time resolution. For each burst analyzed, we use a linear fit to model background in each of the four discriminator channels. These fits are subtracted from the data to obtain background subtracted count rates R_i , where R_1 corresponds to the count rate in discriminator channel 1 (20–50 keV), R_2 corresponds to channel 2 (50–100 keV), R_3 corresponds to channel 3 (100–300 keV), and R_4 corresponds to channel 4 (> 300 keV). A linear fit is sufficient over the short timescales involved here. We define two parameters, a hardness ratio HR and a softness ratio SR :

$$HR = \frac{R_3 + R_4}{R_1 + R_2} \quad \text{and} \quad SR = \frac{R_1}{R_2 + R_3} \quad (1)$$

These ratios are calculated over a time interval containing significant rates above background. We define intensity as the sum over the four energy channels of the background-subtracted count rates. To measure the association of HR and SR with intensity, we calculate the linear correlation coefficient r and $P_c(r, N)^5$. $P_c(r, N)$ is the probability of measuring a linear correlation coefficient greater than or equal to r from two completely uncorrelated data sets, each having N data points. A small value of $P_c(r, N)$ indicates a significant r .

RESULTS

A total of 23 gamma-ray bursts were analyzed. Examples of the evolution of the parameters HR and SR through time are shown in Figures 1–4. 1σ error bars are plotted on the data; when a data point drops to zero, or negative (possible because rates are background subtracted), 2σ upper limits are plotted. The burst intensity time history is the bottom curve of each figure. Figure 1 shows an example of a burst exhibiting indications of correlation between HR and intensity, calculated on a 4 ms timescale. Figure 2 shows a burst exhibiting indications of a correlation between HR and the intensity, as well as indications of anticorrelation between SR and intensity, both calculated on a 64 ms timescale. Figure 3 shows an example of a burst characterized by hard-to-soft evolution throughout the event, indicated by the evolution of both HR and SR , calculated on a 16 ms timescale. Figure 4 shows an example of hard-to-soft spectral evolution, on a 1 ms timescale, through an intense single pulse (FWHM ≤ 3 ms) occurring within a longer burst (FWHM ~ 150 ms).

Table 1 gives the results of the search for correlations between either HR or SR and burst intensity. The first two columns give the BATSE trigger number and the corresponding BATSE Burst Catalog name for each burst analyzed. The third column indicates the time resolution of the data used in the calculation of HR and SR . The fourth and fifth columns give the correlation coefficient r and significance $P_c(r, N)$ resulting from the comparison of HR and burst intensity. The last two columns give r and $P_c(r, N)$ resulting from the comparison of SR and burst intensity.

CONCLUSIONS

There seems to be a significant correlation between HR and the burst intensity for those bursts analyzed on a 64 ms timescale. In addition, these same events seem to show a significant anticorrelation between SR and burst intensity on the same timescale. When one looks at the results for those bursts analyzed on timescales less than 64 ms, it seems that a correlation between

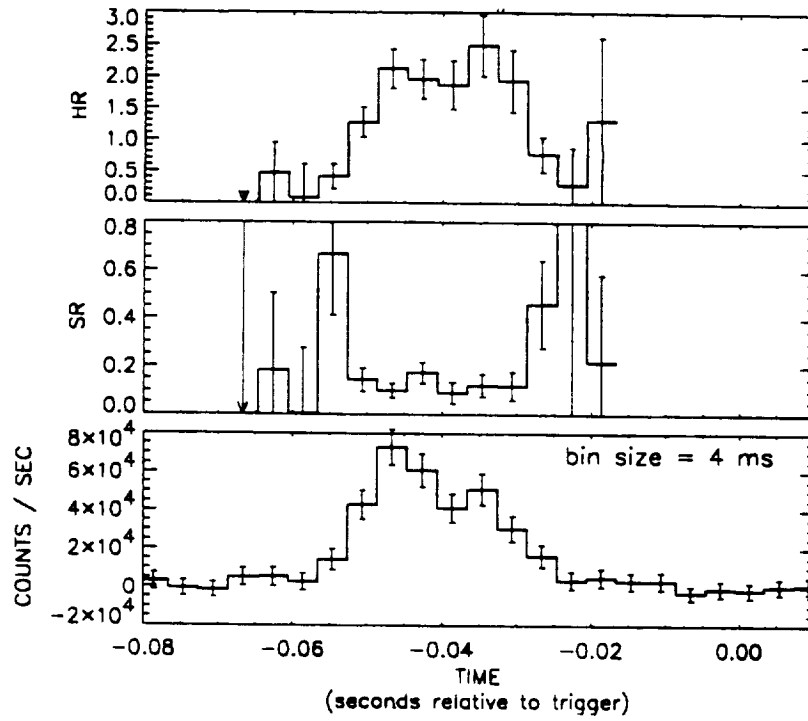


Figure 1. Spectral variations in Burst 432.

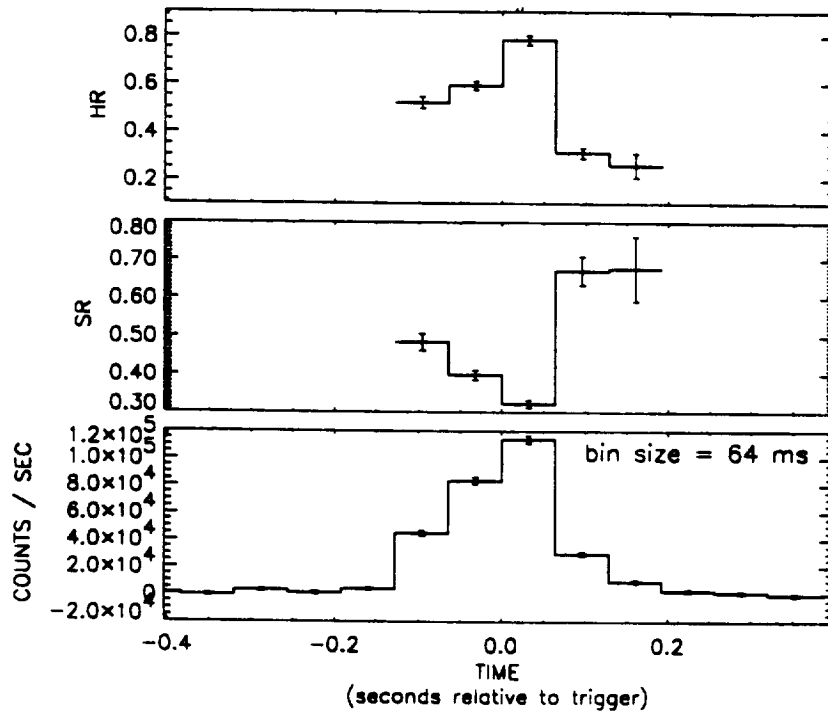


Figure 2. Spectral variations in Burst 444.

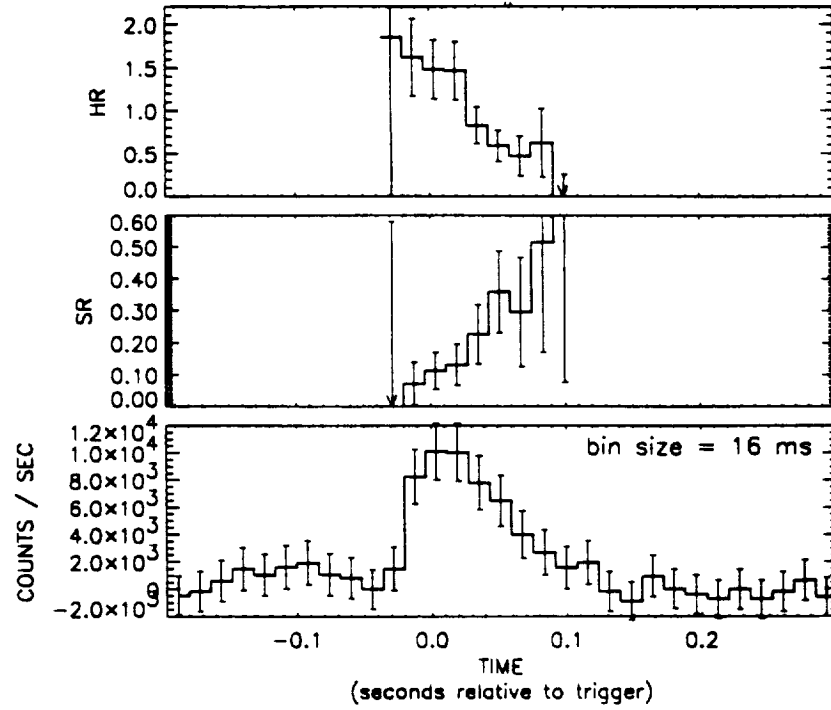


Figure 3. Spectral variations in Burst 1308.

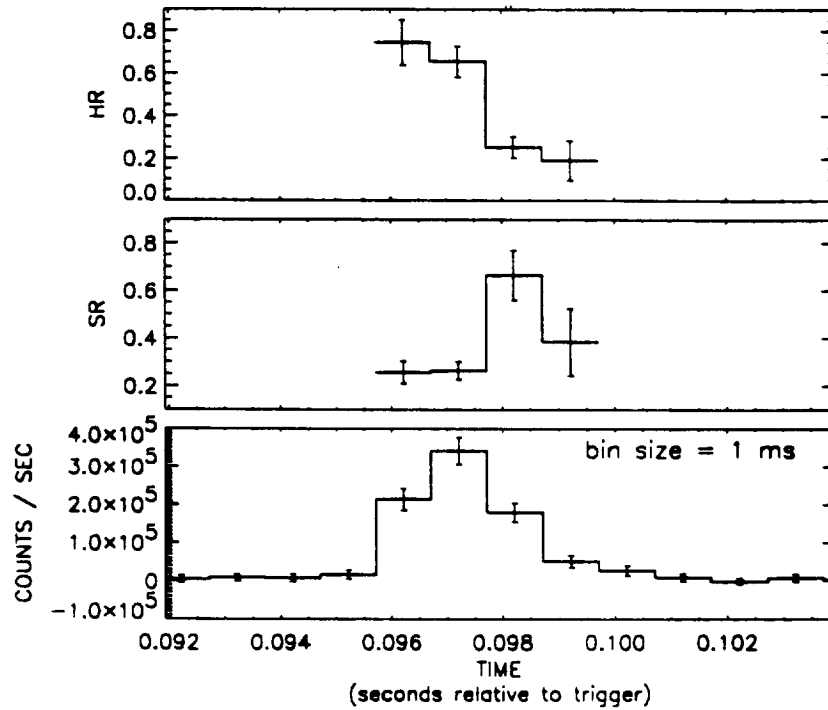


Figure 4. Spectral variations in Burst 1453.

HR and burst intensity is an occasional case, rather than a rule. A significant correlation between *SR* and burst intensity seems to be much less common on these shorter timescales; in fact many of these bursts give values for r and $P_c(r, N)$ that are consistent with zero correlation.

Table I. Spectral/Intensity Correlations						
TRIGGER	BURST	BINSIZE	HARDNESS	RATIO	SOFTNESS	RATIO
NUMBER	NAME	(ms)	r	$P_c(r, N)$	r	$P_c(r, N)$
138	910502B	32	0.689	0.009	0.307	0.307
207	910518	4	0.715	0.007	0.507	0.245
298	910609	64	0.654	0.078	-0.246	0.557
353	910614	16	0.759	0.003	0.530	0.176
432	910625	4	0.842	0.0003	0.171	0.576
444	910626	64	0.969	0.006	-0.953	0.012
547	910717B	64	0.826	0.006	-0.698	0.036
551	910718	64	0.985	0.002	-0.720	0.170
575	910725	64	0.816	0.014	-0.808	0.015
729	910827	16	0.090	0.791	0.191	0.574
788	910912	16	0.859	0.0007	0.225	0.505
799	910916	8	0.454	0.138	0.129	0.690
830	910928	8	0.378	0.080	-0.102	0.648
1073	911117B	64	0.784	0.215	-0.965	0.034
1088	911119	64	0.980	0.126	-0.898	0.290
1096	911120C	64	0.964	0.171	-0.990	0.090
1097	911120B	16	-0.664	0.104	0.698	0.081
1112	911123B	16	-0.104	0.576	0.005	0.787
1289	920110C	64	0.547	0.053	-0.121	0.694
1308	920121	16	0.228	0.586	-0.263	0.529
1453	920229	8	0.008	0.970	0.097	0.657
1463	920305B	8	-0.386	0.125	-0.227	0.380
1482		4	0.709	0.00007	-0.451	0.023

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IDENTIFICATION OF EVENTS OBSERVED BY BATSE

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ABSTRACT

The Burst and Transient Source Experiment (BATSE) on the Compton Gamma Ray Observatory (GRO) routinely observes events which are classified into one of six categories: gamma-ray bursts, solar flares, magnetospheric events, Cygnus X-1 or other known source fluctuations, unknown events, and soft gamma repeaters. The use of BATSE's eight independent detectors enables us to confidently distinguish between these classes, with approximately 25% of recorded triggers being classified as gamma-ray bursts. Methods of classification of events are presented. An analysis of previously classified triggers is discussed, and an estimate of the fraction of events which have been incorrectly identified is given.

INTRODUCTION

The Burst and Transient Source Experiment (BATSE) on the Compton Gamma Ray Observatory (GRO) is an eight-component detector system capable of nearly full-sky observations. This unique design, explained in detail elsewhere,^{1,2} provides unprecedented opportunity to observe the gamma-ray sky. Briefly, each of the eight independent detector modules, mounted on the eight corners of the GRO spacecraft, consists of two NaI(Tl) scintillation detectors: a large area detector (LAD), optimized for temporal resolution, and a spectroscopy detector (SD), optimized for energy resolution.

A consequence of the nearly 4π field of view of BATSE is the large number of events which are observed. These events are analyzed daily, and assigned to one of six categories: gamma-ray bursts (GRBs), solar flares, magnetospheric events, discrete source fluctuations, unknown events, and soft gamma repeaters (SGRs). Several criteria are used in conjunction to discriminate among these categories and to ensure that each event is classified correctly.

SOLAR FLARES

The BATSE experiment is able to use its eight independent detector modules to obtain an approximate location of an event. The method of event localization is explained by Brock et al.³ Localization to a point near the known location of the Sun is a strong indication that an event could be of solar origin.

Many flares observed by BATSE can be confirmed by simultaneous observation by the Geostationary Operational Environmental Satellites (GOES).†

† GOES data is routinely published in Solar-Geophysical Data prompt reports, available from the National Oceanic and Atmospheric Administration.

The appearance of an event in the GOES data, combined with the BATSE location, enables one to classify an event as a solar flare with confidence. Of 485 solar flares recorded by BATSE, approximately 77% have been confirmed by the GOES data.

The BATSE detector system employs four-channel discriminators that span the approximate energy ranges (in keV) of 20–50, 50–100, 100–300, and above 300. Since the majority of solar flares have soft spectra relative to GRBs, events clearly observed in channel 4 (above ~ 300 keV), and not visible in the GOES data, are not likely to be solar flares. Those events that are not apparent in the GOES data, but that exhibit little or no emission above ~ 300 keV and localize near the Sun, are generally classified as solar flares. Many BATSE flares show no emission above 100 keV.

MAGNETOSPHERIC EVENTS

The BATSE instrument is occasionally triggered by bremsstrahlung radiation from charged particles. Frequently, these particles exhibit their spiral motion along magnetic field lines. This appears in the eight LADs as similar count rates in opposite facing detectors, indicating that the detected radiation is produced in or near the spacecraft. Although an intense GRB can also sometimes be seen in all eight detectors due to scattering of gamma-rays off the atmosphere of Earth, the flux through the Earth-facing detectors is significantly less than that through the detectors that directly observe the burst.

Radiation from charged particle interactions at some distance from GRO also may be detected. This appears as elevated count rates in four detectors on the same side of the spacecraft. The locations of these events are near the horizon of Earth. Unlike GRBs, the count rates peak at different times in each detector.

The GRO position at the time of an event aids in identifying charged particles. Figure 1 shows the GRO position during magnetospheric events.

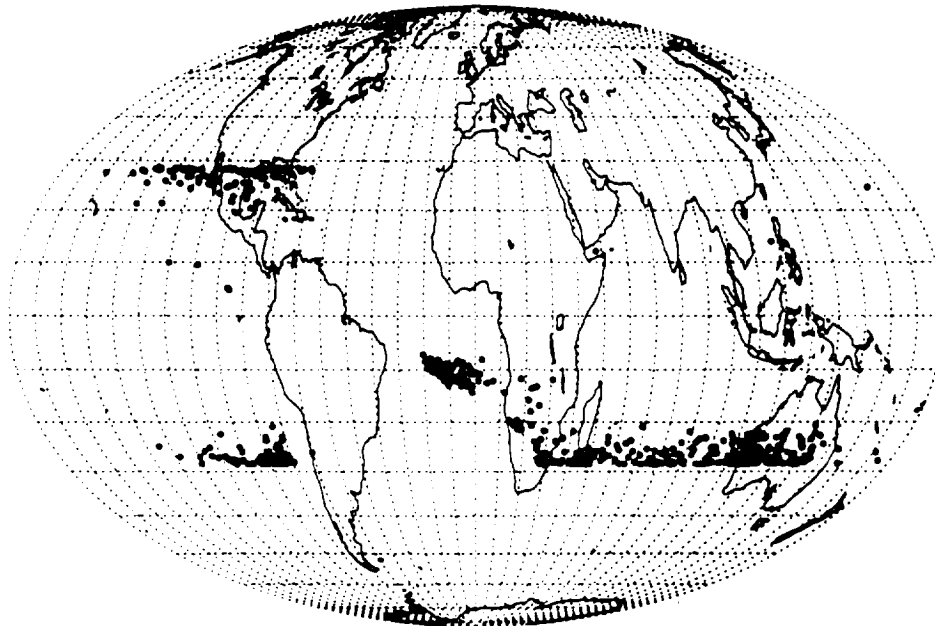


Figure 1. GRO Location During Magnetospheric Events.

These events are shown to cluster near high latitudes and the SAA, while GRBs and solar flares are isotropically distributed throughout the orbit. The effects of the powerful NWC VLF transmitter, located at $\sim 114^\circ\text{E}$ on the coast of western Australia and known to cause charged particles to precipitate into the atmosphere,^{4,5} are clearly evident in Figure 1.

DISCRETE SOURCE FLUCTUATIONS

- Cygnus X-1

Prior to the outburst of the hard x-ray transient GROJ0422+32,⁶ all discrete source fluctuations that triggered BATSE were due to the binary x-ray source Cygnus X-1. Normally the variations of Cyg X-1 are not large enough to meet the BATSE trigger criteria. Occasionally, the source flares enough to cause the instrument to trigger. These events can be identified from their locations and the fact that the source is visible to BATSE at the time of the trigger. BATSE also sometimes enters trigger mode when a source emerges from behind the limb of Earth. These events are easily classified since they appear as occultation steps at predictable times.

- GROJ0422+32

During the period of strong emission from the source GROJ0422+32, BATSE recorded an excess number of triggers from this location. The majority of these triggers occurred as the source emerged from behind the Earth, resulting in confident classification of these events. Fluctuations of this source also induced triggers; these were identified by their locations and their soft spectra relative to GRBs.

UNKNOWN EVENTS

Of 1800 events observed, only eight have been placed in this category. Five are very short duration events, of which four have locations consistent with a point source below the horizon of Earth. This cannot be accounted for by an error in the location algorithm, since BATSE burst locations agree with those of the Interplanetary Network. Lack of data due to the failure of the on-board tape recorders accounts for two. The remaining event has been placed in this category due to ambiguity in the location estimate.

SOFT GAMMA REPEATERS

BATSE has currently categorized three events as SGRs. These events are identified primarily by their extremely soft spectra (characteristic energies of ~ 30 keV) and typical durations of ~ 0.1 second.⁷ Although the SGRs classified by BATSE appear to originate from the same source, the criteria of a soft, exponential spectrum, short duration, and frequently, a flat-topped temporal profile should enable confident identification of any previously unobserved repeaters.

GAMMA-RAY BURSTS

The BATSE instrument observes ~ 0.85 gamma-ray bursts per day. One criterion helpful in identifying GRBs is the spectral hardness of these events.

Events classified as GRBs show emission above 100 keV, and frequently are observed above 300 keV. An analysis of 248 BATSE GRBs shows that approximately 51% of these events have emission above 300 keV, while a similar analysis of 390 BATSE solar flares shows that approximately 14% have emission above 300 keV.

The independent detectors also aid in classifying events which are candidates for GRBs. An event which has similar count rates in opposite detector pairs is not likely to be a burst. Figure 2 shows the count rate ratio $\frac{C_{opp}}{C_{bright}}$ for three types of events, where C_{bright} is the count rate in the brightest detector, and C_{opp} is the count rate in the detector opposite to the brightest. The figure clearly indicates that magnetospheric events separate into two general classes. Those with a ratio $\simeq 1$ induce similar count rates in opposite-facing detectors, while those with a ratio $\simeq 0$ are due to radiation emitted at some distance from the spacecraft. GRBs and solar flares have ratios clustered about zero, indicating that the count rate in the brightest detector is much larger than that in the opposite detector.

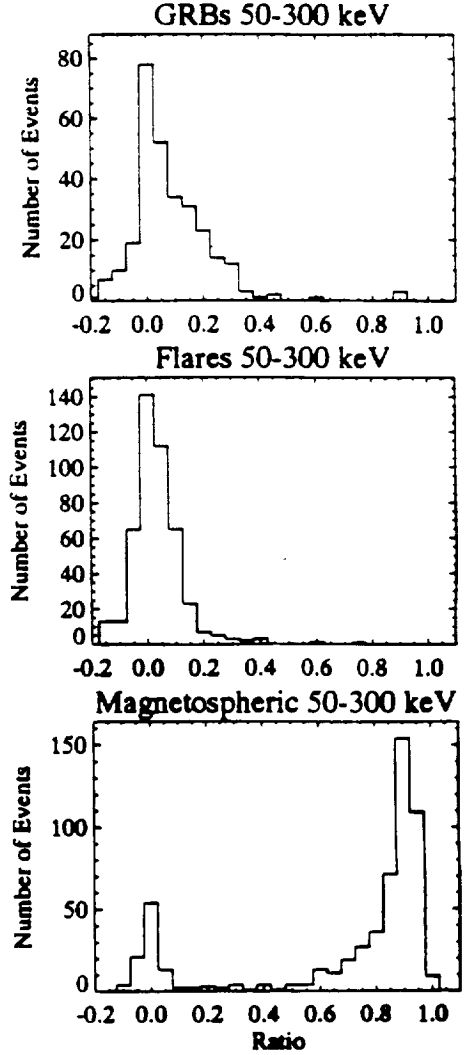


Figure 2. Count Rate Ratios ($\frac{C_{opp}}{C_{bright}}$) for Several Types of Events.

ESTIMATES OF MISCLASSIFICATION OF EVENTS

The BATSE systematic location error is currently estimated to be $\sim 2.5^\circ$. Since GRBs are measured to be isotropically distributed, one expects $\sim 1.1\%$ of total bursts observed to be within 12° of the Sun. Thus of 424 bursts observed, ~ 5 bursts should locate within 12° of the Sun. BATSE has classified as GRBs only two events which locate within 12° of the Sun. These data suggest that approximately $3 (\pm 3)$ GRBs have been classified as solar flares due to their proximity to the Sun. Conversely, since only two GRBs locate near the Sun, a maximum of two solar flares may have been classified as bursts.

Results of a Bayesian statistical analysis of events originating from the direction of Cygnus X-1 indicate that probably zero GRBs have been incorrectly identified as being due to the discrete source, and approximately three true Cyg X-1 events have been placed in the category of GRBs.⁸ A similar analysis has not been performed on events due to the new source GROJ0422+32, since the majority of these events occurred as the source was emerging from behind the Earth. This source has been active for ~ 60 days; an average of 0.85 bursts per

day indicates that ~ 1 burst should have been detected within 12° of the source. During this period, zero bursts were detected within this region, implying that it is possible that one GRB has been incorrectly identified as a fluctuation of GROJ0422+32. A summary of misclassification estimates is given in Table I.

Table I. Estimates of Misclassification		
<i>Type</i>	<i>Misclassified as</i>	<i>Number</i>
GRB	Solar flare	$\sim 3 (\pm 3)$
GRB	Cygnus X-1	~ 0
GRB	GROJ0422+32	≤ 1
Flare	GRB	≤ 2
Cygnus X-1	GRB	~ 3

SUMMARY

Solar flares are easily classified using the BATSE location, the energy range in which the event is apparent, and frequently, the appearance of the event in GOES data. Magnetospheric events are distinguished by similar count rates in opposite detector pairs or by rates in four detectors with the peak rates occurring at different relative times. These events also tend to occur when GRO is at high latitude or near the SAA, and often exhibit broad, smooth temporal profiles. Discrete source fluctuations have known locations in the sky, enabling one to recognize these events with relative ease. However, a Bayesian statistical analysis is performed on events which are thought to be due to fluctuations of Cyg X-1, since GRBs can randomly appear from the same location. Triggers due to sources entering the field of view of BATSE appear as occultation steps in the relevant detectors. Eight of 1800 recorded events are unknown. Soft gamma repeaters are identified by their soft spectra and by repetitive consistent locations. Gamma-ray bursts are distinguished from other events by the energy range of emission and locations not consistent with those of the Sun or other known sources of x-ray or gamma-ray emission.

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HARD X-RAY TRANSIENT

W. S. Paciesas and M. S. Briggs, University of Alabama, Huntsville; B. A. Harmon and R. B. Wilson, Marshall Space Flight Center, NASA; and M. H. Finger, Computer Sciences Corporation, report for the BATSE team: "We have detected a strong transient hard x-ray source in data from the BATSE instrument on the Compton Gamma Ray Observatory. The location is estimated to be at R.A. = 4h.4, Decl. = +32 (equinox 2000.0), with an error radius of about 1.5 deg. The source was first detected at an intensity of about 0.2 Crab (20-300 keV) on Aug. 5. By the end of Aug. 8, the flux had reached about 3 Crab and was still increasing. The spectrum is fairly hard (power-law number index about 2), with significant flux out to at least 300 keV. Although the intensity shows strong variability on short timescales, no periodicity is evident. Follow-up observations are encouraged."

CYGNUS X-1

L. Angelini and N. E. White, Laboratory for High Energy Astrophysics, Goddard Space Flight Center, NASA; and L. Stella, Osservatorio Astronomico di Brera, Milan, report: "We have independently discovered 0.04-Hz quasi-periodic oscillations from Cygnus X-1. This result comes from an ongoing detailed analysis of 13 EXOSAT 1- to 20-keV Medium Energy (ME) detector x-ray observations made between 1983 and 1986. Power spectra made from the ME timing data are complex. The typical power spectrum is flat from 0.001 Hz up to a break frequency that varies between 0.1 and 0.3 Hz from observation to observation. Above this break frequency, the power spectrum decreases with a slope of about 1. Superposed on this power law, there is low-level structure that on occasions appears as a broad excess, the peak of which varies between 0.7 and 2 Hz from observation to observation. In a few power spectra, there is also low-frequency noise below 0.001 Hz caused by absorption dips and long-term changes in intensity on timescales of hours. A QPO peak is clearly present at 0.04 Hz, with a FWHM of about 0.07 Hz, in four of the 13 observations (1983 July 28, 1985 Aug. 12, Oct. 15, and Oct. 18). This seems to be similar to the 0.04-Hz QPO reported on IAUC 5576 at energies above 20 Kev. The appearance of this QPO peak is not correlated with the overall source intensity state, or orbital phase. However, it is most prominent when the break frequency is at its lowest value (about 0.1 Hz) with the QPO peak straddling the break."

Studies of hard X-ray source variability using BATSE

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Received June 3; accepted July 17, 1992

Abstract. — The BATSE large-area detectors on the Compton Observatory can be used to monitor the variability of x-ray and gamma-ray sources on timescales longer than a few hours using the Earth occultation technique. Spectral information is collected in 16 channels covering the energy range from ~ 25 to 2000 keV. Approximately 20 of the strongest sources are currently being monitored on a daily basis as part of standard BATSE operations. We discuss observations of the Crab Nebula, Cen A, and the Galactic Center as examples of the current BATSE capabilities.

Key words: X-rays: general — Gamma rays: observations — Methods: data analysis.

1. Introduction.

Though designed primarily as a sensitive detector of gamma-ray bursts, the Burst and Transient Source Experiment (BATSE) has useful capabilities as a near-all-sky monitor for other hard X-ray and low energy gamma-ray sources. Sufficiently bright persistent and long-term transient sources are detected using the Earth occultation technique (Paciesas *et al.* 1985; Fishman *et al.* 1990). During each *Compton* orbit, the Earth is seen by BATSE to sweep across a band in the sky extending $\sim 35^\circ$ above and below the orbit plane. As each source enters into (exits from) occultation by the Earth, count rates in the source-facing detectors decrease (increase) according to the source intensity. Although few sources are bright enough to show statistically significant single-occultation steps,¹ the sensitivity is greatly enhanced by combining data from many orbits. One of the first results using this technique was the discovery of an outburst of the recurrent transient GX339-4 (Fishman *et al.* 1991; Harmon *et al.* 1992).

In principle, the limiting sensitivity may be arbitrarily improved by including longer pre- and post-occultation background intervals and increasing the number of orbits accumulated. In practice, systematic errors due to source confusion, imperfect knowledge of background variations and detector response, and other effects are the effective

limit on sensitivity. In the following sections we present preliminary results obtained from the occultation analysis and discuss their significance in the context of understanding systematic effects.

2. Instrumentation and data analysis.

BATSE consists of eight identical modules located at the corners of *Compton*. The octahedral arrangement of the modules and the relatively thin (1.27 cm) large-area ($\sim 2,000$ cm²) NaI(Tl) detectors in each module are optimized for gamma-ray burst detection and localization. However, these same properties provide important capabilities for observations of other types of sources by detecting their coherent pulsations and/or by detecting their occultations by the Earth.

The occultation technique is presently being used for two complementary purposes during the daily BATSE quick-look scientific analysis. Firstly, a catalog of known bright source candidates is routinely used as input to software which calculates the source occultation times and fits a simple step function model with a polynomial background to the data at each occultation. In most cases, the separate occultation steps are summed on one-day timescales to produce a spectrum for each source. The results reported herein are derived from these one-day summations. Secondly, the data are also searched daily for occultation steps due to sources not included in the previous analysis. This approach is obviously necessary

¹ Cygnus X-1 and the Crab Nebula are the typical exceptions above 50 keV.

for detecting the transient outbursts from previously unknown or unsuspected sources. Once such a detection has been made, the software provides an approximate source location with which the intensity and spectrum of the new source are determined in the manner of the catalog sources. Additional details of the methodology are discussed by Harmon *et al.* (1992).

The analysis uses 16-channel spectra which are read out every 2.048 s for each detector. The energy widths range from \sim one-half of the detector resolution at low energies to \sim twice the detector resolution at high energies. This binning is convenient for use with model-independent spectral deconvolution techniques. The spectral results which we present below are obtained by simple inversion of the detector response. We have disregarded the lowest channel because of threshold effects and the highest channel because of calibration uncertainties.

3. Preliminary results.

The Crab Nebula is unique among hard X-ray sources as a standard reference because of its hard spectrum and effectively constant intensity. For occultation purposes it has the additional advantage of location away from other bright sources. We show in Figure 1 the recent time history of the Crab flux as determined from occultation data. Deviations of $\sim 10\%$ from a constant intensity are evident in the figure. These appear to be due mainly to imperfect knowledge of the channel-to-energy conversion. Efforts to improve the channel-to-energy conversion algorithm are ongoing. Figure 2 shows our deconvolved Crab spectrum from the pointing interval spanning Truncated Julian Days (TJD) 8659–8672, compared with the HEAO-1 best-fit Crab spectrum (Jung 1989). The agreement with the HEAO-1 spectral shape is good, whereas the normalizations differ by $\sim 10\%$.

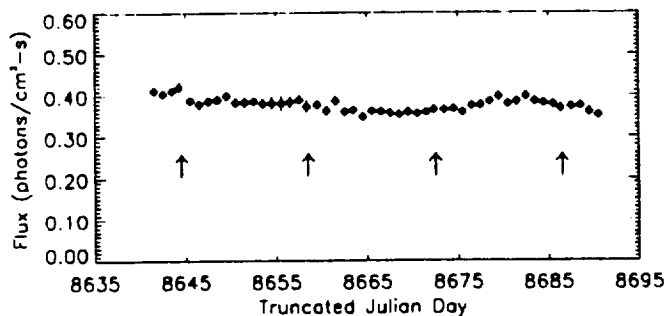


FIGURE 1. Crab Nebula flux measured by BATSE using the occultation technique. The energy range is 20–2000 keV. Arrows indicate times of spacecraft reorientation.

The giant radio galaxy Centaurus A is a somewhat weaker source which is also located in a relatively uncrowded region. Figure 3 shows the measured raw count

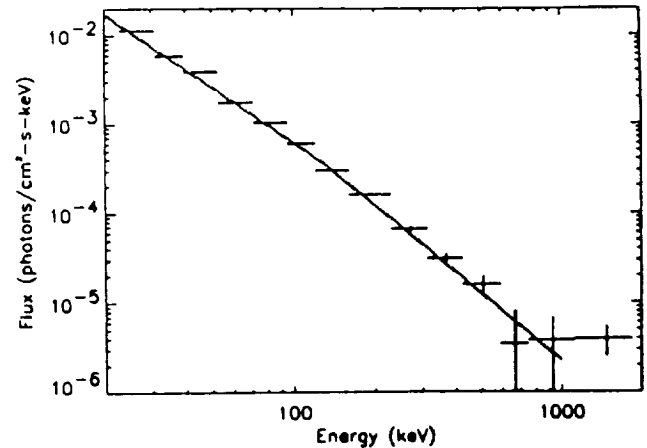


FIGURE 2. Crab Nebula spectrum for TJD 8659–8672. The data are deconvolved by inverting the detector response matrix. The solid line is the best-fit spectrum measured by HEAO-1 (Jung 1989).

rate from Cen A in the energy range 35–100 keV for an interval of ~ 50 days. During this interval the source appears to show relatively constant intervals of 5–10 days at a low intensity, interspersed with flaring episodes during which the intensity increases by as much as a factor of 4.

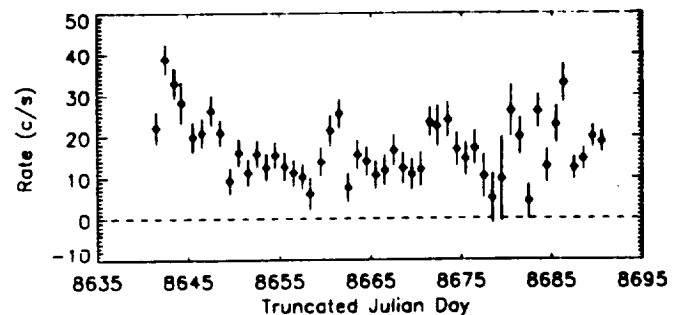


FIGURE 3. Cen A count rate history. The energy range is 35–100 keV.

The Galactic center region presents one of the most difficult challenges for the occultation technique. SIGMA observations (Sunyaev *et al.* 1991) have shown that at least three variable sources contribute significantly to the hard X-ray flux from this region: 1E1740.7–2942, GX1+4, and GRS1758–258. The sources are located $\sim 6^\circ$ from each other, forming a roughly equilateral triangle. This separation is in principle large enough to allow the sources to be distinguished in the occultation analysis and the software computes fluxes for each of these sources separately. Nevertheless, confusion due to activity by other sources in the region is possible. Figure 4 shows raw rate histories of 1E1740 and GX1+4 during the same 50 day interval. 1E1740 shows a low but significant level of flux most

of the time and an apparent strong outburst beginning around TJD 8680. Contemporaneous imaging observations by SIGMA (Schmitz-Fraysse *et al.* 1992; Gilfanov *et al.* 1992) indicate that 1E1740 was relatively constant but the nearby source GX 354-0 became active sometime between TJDs 8671 and 8682. The occultation geometry at this time was such that GX 354-0 cannot be clearly separated from 1E1740. We conclude that most or all of the outburst activity visible in our data during this interval is probably caused by GX 354-0.

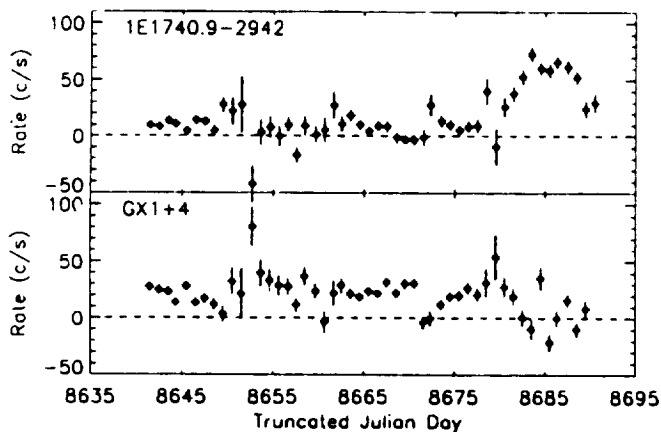


FIGURE 4. Count rates detected from two Galactic Center sources (35–100 keV). Larger error bars typically indicate times of source confusion.

Figure 5 shows a spectrum of 1E1740 obtained during the lower intensity state. This is near our current sensitivity limit for a 14-day accumulation. The hard-state spectrum measured by SIGMA (Bouchet *et al.* 1991) in October, 1990, is shown for comparison. The BATSE data clearly lie below the SIGMA spectrum and are closer to the low-state of 1E1740 seen by SIGMA in the spring of 1991 (Sunyaev *et al.* 1991). Schmitz-Fraysse *et al.* (1992) report SIGMA observations of 1E1740 on TJDs 8670, 8674, and 8675 at a level of 45 mCrab which is consistent with the BATSE data in Figure 5. Although these are not quite contemporaneous, Figure 4 indicates that the BATSE measurements on those days do not differ significantly in intensity from the interval shown in Figure 5. The BATSE data show no indication of the high-energy feature detected by SIGMA in October, 1990.

4. Conclusions

These preliminary results attest to the importance of BATSE as a sensitive near-all-sky monitor in the hard x-ray and low-energy gamma-ray range. Even in a crowded region such as the Galactic Center, it appears that the Earth occultation technique can be used to monitor the known bright sources and detect the occurrence of

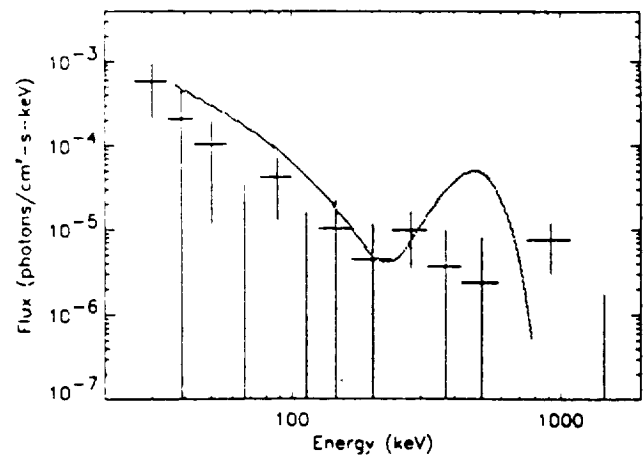


FIGURE 5. Spectrum of 1E1740.7-2942 during the interval TJD 8659–8672. The solid curve is the best-fit “hard” state spectrum measured by SIGMA in October, 1990 (Bouchet *et al.* 1991). The SIGMA “normal” state is essentially the same as the “hard” state below ~ 150 keV.

anomalous behavior in the region. The efforts underway (Wheaton *et al.* 1992) to enhance the occultation technique should allow us to extend the BATSE monitoring capabilities to weaker sources as well as to reduce source confusion in crowded regions.

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MONITORING THE LONG-TERM BEHAVIOR OF ACTIVE GALACTIC NUCLEI USING BATSE

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ABSTRACT

The variability of hard x-ray/low-energy gamma-ray emission from active galactic nuclei (AGNs) has important implications for understanding the physical processes powering these sources. Use of the Earth occultation technique allows nearly continuous monitoring of sufficiently bright AGNs by BATSE. We have recently reprocessed a portion of the data base using an improved occultation algorithm and present preliminary results for a sample of eight AGNs known or suspected to emit above 20 keV. The sources Cen A, NGC 4151 and 3C 273 are routinely detected with $> 4\sigma$ statistical significance in 14-day accumulations. We present spectra of these sources for periods when they were observed by other *Compton* instruments. We investigate the time variability of Cen A and NGC 4151 and find marginal evidence for anti-correlation between spectral hardness and intensity.

INTRODUCTION

Prior to the launch of *Compton*, observations of AGNs were sparse and only a few sources had clearly been detected (see ref. 1 for a recent review). However, the observations were sufficient to show that at least some of the time AGNs emit most of their energy in gamma-rays. Similarities in the x-ray and gamma-ray properties of AGNs and Galactic black-hole candidates^{2,3} may reinforce the arguments in favor of black-hole models for both types of sources, indicating that the physical mechanism powering these sources operates over a range of many orders of magnitude in black-hole mass. Furthermore, the "average" properties of AGNs are important for evaluating the contribution of unresolved point sources to the diffuse x-ray and gamma-ray backgrounds (e.g., ref. 4).

We are also studying AGNs in order to evaluate systematic effects in the BATSE occultation analysis. The AGN spectra are sufficiently hard that intercalibration with other instruments, particularly OSSE, will allow confirmation of BATSE's capability for measuring weak sources.

OBSERVATIONS

The Earth occultation technique which enables us to use BATSE as a near-all-sky monitor is continually being refined as our understanding of systematic effects advances. The basic technique and some of the systematics have been discussed elsewhere.^{5,6} We use data from the large-area detectors (LADs) which provide 2.048 s time resolution in 16 energy channels. Rates near each source occultation are fitted with a model assuming a source immersion/emersion su-

perimposed on a quadratically varying background, with additional terms for other potentially bright sources whose occultation times are sufficiently close. We have recently revised the software to use the energy-dependent atmospheric transmission in fitting each occultation step and to use more conservative criteria for rejection of interfering sources.

We have thus far reprocessed data from the beginning of the mission (TJD 8369) through TJD 8500. A catalog of 42 sources was used, including eight AGNs selected on the basis of previous measurements or extrapolations from lower energy data.^{2,7} The reprocessed interval includes viewing periods 3 and 4 (TJD 8422–8449), during which 3C 273 and NGC 4151, respectively, were *Compton* primary (*z*-axis) targets. A portion of viewing period 8 (TJD 8490–8501), during which 3C 273 was an OSSE secondary (*x*-axis) target, is also covered. Since the *Compton* observation of Cen A did not occur until viewing period 12 (TJD 8546–8560), we reprocessed this interval specially for Cen A in order to provide a larger sample for intercalibration.

One complication with BATSE occultation analysis results from the satellite reorientations. Simple count rate histories are of limited use in long-term source monitoring because the effective exposure to a given source changes with each viewing period; the count rate spectra must be converted to incident flux in order to measure the true source variability. For this analysis, we deconvolved the 16-channel count rate spectra by folding a power-law spectrum $dN/dE = A_{80}(\frac{E}{80 \text{ keV}})^{-\alpha}$ through the appropriate detector response matrix and determining the best-fitting spectral index α and normalization A_{80} by χ^2 minimization. The flux was calculated by integration of the fitted power-law. We are not yet able to fit spectra from more than one viewing period simultaneously.

We derived a simple intercomparison of the sources in the sample by computing their fluxes during each viewing period assuming $\alpha = 2$. Table I summarizes the fluxes we measured for each source during viewing periods 3 and 6. The fluxes for Cen A, NGC 4151, and 3C 273 are typical of those derived at other times, with routine detections of $> 4\sigma$ statistical significance. The relatively strong signal seen from MCG–5-23-16 during viewing period 6 is atypical and may reflect a systematic error; we do not yet claim a detection of this source.

Table I. Intensities of Selected AGNs		
Source	20–320 keV Flux (10^{-3} ph/cm ² -s)	
	TJD 8422–8435 (viewing period 3)	TJD 8463–8476 (viewing period 6)
* 3C 273	9.2 ± 1.4	4.7 ± 1.1
? 3C 279	1.4 ± 1.5	1.5 ± 1.1
* Cen A	36 ± 1.4	25 ± 1.8
? IC 4329a	2.4 ± 1.7	2.8 ± 1.4
? MCG–5-23-16	-1.0 ± 1.4	6.2 ± 1.2
* NGC 4151	12 ± 1.2	14 ± 1.1
? NGC 5506	-1.7 ± 1.5	3.3 ± 1.2
? NGC 7582	2.1 ± 1.0	1.9 ± 1.1

* positive detection ? uncertain at present

For intercalibration we computed spectra for Cen A, NGC 4151, and 3C 273 at times coincident with *Compton* *z*-axis pointings. Figures 1a–c show

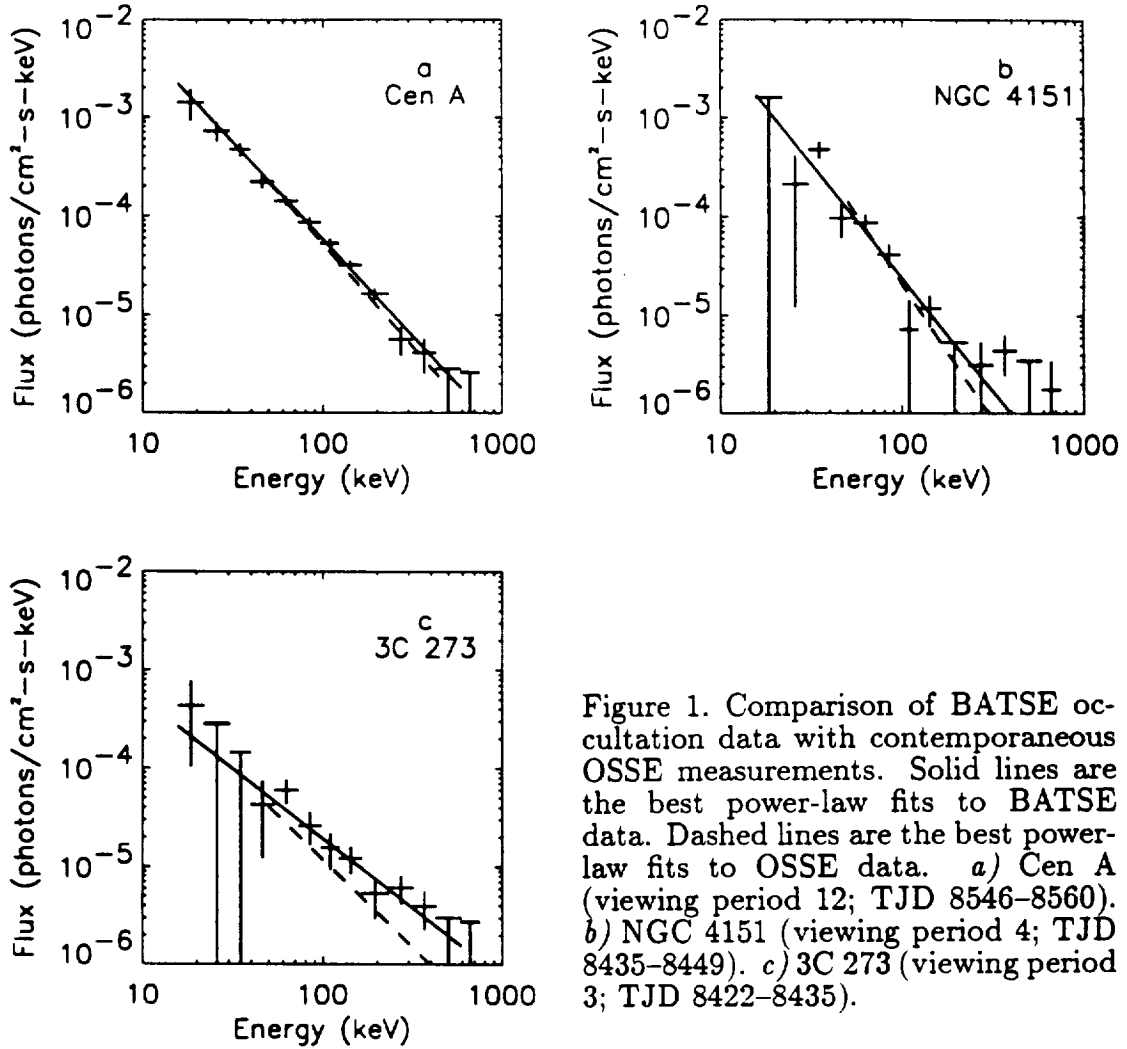


Figure 1. Comparison of BATSE occultation data with contemporaneous OSSE measurements. Solid lines are the best power-law fits to BATSE data. Dashed lines are the best power-law fits to OSSE data. *a*) Cen A (viewing period 12; TJD 8546–8560). *b*) NGC 4151 (viewing period 4; TJD 8435–8449). *c*) 3C 273 (viewing period 3; TJD 8422–8435).

the results together with best-fitting single power-law models. For Cen A, we find $\alpha = 1.96 \pm 0.07$ and $A_{80} = (9.1 \pm 0.4) \times 10^{-5}$ ph/cm²-s-keV ($\chi^2 = 13.4$ for 11 d.o.f.). For NGC 4151, $\alpha = 2.3 \pm 0.2$ and $A_{80} = (4.0 \pm 0.5) \times 10^{-5}$ ph/cm²-s-keV, although the fit is poor ($\chi^2 = 20.1$ for 11 d.o.f.). For 3C 273, $\alpha = 1.4 \pm 0.2$ and $A_{80} = (2.6 \pm 0.5) \times 10^{-5}$ ph/cm²-s-keV ($\chi^2 = 10.0$ for 11 d.o.f.).

Cen A and NGC 4151 are sufficiently strong for us to be able to investigate their variability in more detail. For example, we summed the count rate spectra over four-day intervals for each source and fitted each interval separately with a power-law, allowing both A_{80} and α to vary. Figures 2*a-b* show the derived α as a function of the source flux. An anti-correlation of spectral hardness with intensity appears to occur in both sources. For Cen A, the effect appears stronger at low intensities and weaker or absent at high intensities. Again, systematic uncertainties require us to consider these results suggestive but preliminary. We plan further investigations of this sort after more of the data have been reprocessed.

The BATSE data for Cen A, NGC 4151, and 3C 273 agree well with more sensitive contemporaneous OSSE measurements^{8–10} shown as dashed curves in

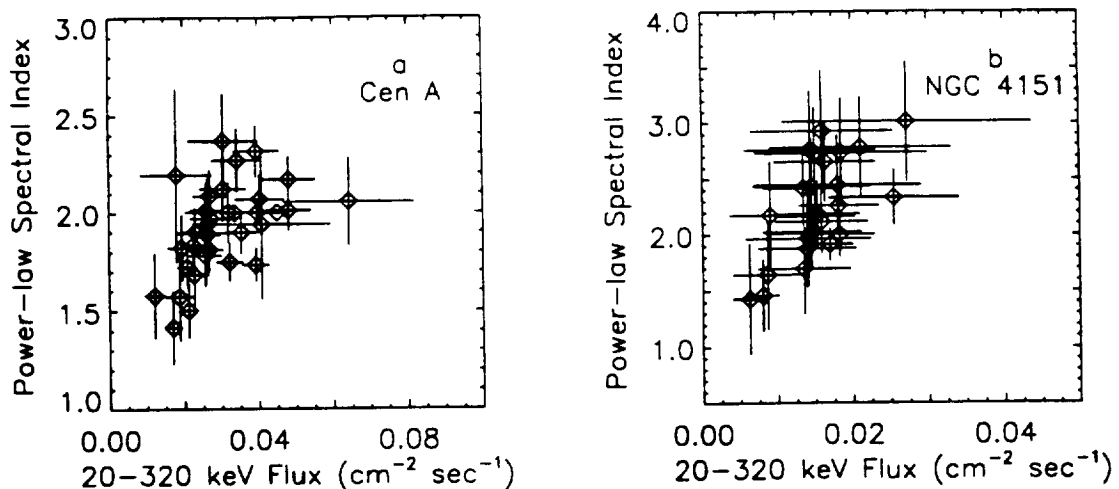


Figure 2. Correlation plots of power-law spectral index *vs* flux in the 20–320 keV energy range for *a*) Cen A and *b*) NGC 4151 in the interval TJD 8369–8498. Spectra were accumulated over four-day intervals. Points of less than 1.5σ significance have been excluded.

Figs. 1*a-c*. The spectral indices for all three sources are in reasonable agreement, considering the differences in energy coverage. The normalizations for Cen A and NGC 4151 are consistent to within $\sim 20\%$, whereas a larger difference ($\sim 40\%$) occurs for 3C 273. We are investigating our systematics in more detail for the latter source.

DISCUSSION

Among our sample of AGNs, three objects (Cen A, NGC 4151, and 3C 273) are strong enough to be detected regularly with good statistical significance on timescales of 14 days or less. These sources have historically been the strongest AGNs in hard x-rays. The fluxes we observe for Cen A are well within the range of pre-*Compton* observations and those of NGC 4151 are typical of post-1977 measurements (cf. ref. 1).

Though widely spaced in time, pre-*Compton* observations have shown that the spectral index of Cen A is remarkably constant (~ 1.6) over a wide range of intensities,¹ whereas our four-day measurements show significant variations ($\sim 1.5 - 2.3$). Although we cannot rule out all possible systematic effects in our data, one possible explanation for this is that our single power-law fit is too simplistic. We note that the OSSE spectra of Cen A during viewing period 12 are well fit by a broken power-law with a break energy around 180 keV.⁸ Our data are also adequately fit by a broken power-law with $\alpha = 1.7 \pm 0.1$ below E_{break} (fixed at 180 keV). The steeper spectra in Fig. 2*a* may thus represent times when the break moves to a lower energy and/or the spectrum above the break becomes steeper, while the spectral index below the break remains constant.

The 2–20 keV photon spectra of Seyfert galaxies are known to be power-laws with spectral indexes clustering in the range 1.5–2.¹¹ We find that the average spectrum of NGC 4151 was softer than this above 20 keV during the period of our observations; if the 2–20 keV spectral index was normal at this time, then a single power-law could not fit the data over the 2–740 keV range. This would be consistent with recent GRANAT observations¹² which show a

break in the spectrum of NGC 4151 around 40 keV. We cannot confirm the existence of such a break from our data alone.

Though our evidence for a hardness/intensity anti-correlation in NGC 4151 is rather weak, similar anti-correlations in the 2–10 keV band have been reported for a number of Seyfert galaxies (ref. 13 and refs. therein), including NGC 4151.^{14,15} Comparable measurements in hard x-rays are generally not available; marginal evidence has been presented for a correlation of opposite sense in NGC 4151 at 100 keV.¹⁶ Our preliminary results tend to support the lower energy measurements.

SUMMARY

With current algorithms, BATSE can monitor the hard x-ray/low-energy gamma-ray behavior of Cen A and NGC 4151 on timescales of several days or less. We find clear evidence for variability of Cen A and weak evidence for variability of NGC 4151 on these timescales during an interval of ~ 130 days in 1991. Although some systematic errors may be present, our data suggest that the variability of both sources is such that softer spectra correlate with higher intensities. We also find that 3C 273 is regularly detectable during this same interval, although its lower intensity constrains our sensitivity for detecting source variability. Among the other AGNs in our sample, we find that several may have intermittent outbursts of significant flux, indicating that a modest improvement in our occultation analysis technique could allow monitoring of considerably more AGNs.

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A STUDY OF GAMMA-RAY BURST CONTINUUM PROPERTIES PRESENTING EVIDENCE FOR TWO SPECTRAL STATES IN BURSTS

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ABSTRACT

Evidence is presented for the existence of two spectral states contributing simultaneously to the total spectrum observed in many gamma-ray bursts (GRB's). An ensemble of 120 GRB's measured by BATSE have been studied, using 4 channel spectral data, to determine in which bursts the spectral states can be most effectively resolved. The technique of summing the low intensity spectra together to get an average spectrum allows for precise characterization of the average low intensity spectral behavior. The 4 and 16 channel spectra obtained by the BATSE Large Area Detectors (LAD's) are analyzed using a model-independent spectral inversion technique. The results of these analyses applied to an individual burst are discussed in detail.

INTRODUCTION

This study performed on BATSE LAD data¹ was initiated after a significant fraction of the DISCLA spectral analysis of the bursts for the BATSE burst catalog had been completed. The catalog analysis showed that in many bursts the low energy spectra (20-100 keV) for the peak fluxes of the bursts were significantly harder than the low energy spectra of the total fluence for the same bursts. These spectral differences suggested that the low intensity spectra in these bursts were significantly different from the high intensity spectra. Here high intensity spectra within a burst are defined as those spectra at or near the peak intensity of the burst. Low intensity spectra are those spectra in a burst that are considerably below the peak intensity. The spectral differences initiated study of the BATSE 4 channel LAD data for 120 GRB's.

The presence of two spectral states manifests itself in two ways in our data. Studies of the 4 channel spectral data in the 20-100 keV range show discontinuous jumps in the hardness ratio vs. intensity plots of spectra in bursts. These jumps are not indicative of simple correlations of hardness ratio with intensity but of the onset of different spectral states at particular intensities within bursts. Also studies of the BATSE 16 channel LAD data show that the most intense spectra in bursts are often inconsistent with a single component origin. In some bursts the lower intensity spectra are consistent with a single spectral component but the higher intensity spectra appear to be a combination of the low intensity component plus some higher energy variable component.

PROCEDURE

The analysis employed DISCSC and PREB¹ data for the bursts. These include 4 channel discriminator data with 64 ms time resolution covering the time interval from 2s before the burst trigger to 240s of seconds after the burst trigger. The energy ranges are 20-50 keV, 50-100 keV, 100-300 keV, and >300 keV. Background subtraction was performed using a quadratic fit to the count rates in each channel of each detector derived from appropriate intervals around the burst. The background fits were inspected by multiple analysts and hardcopy outputs were produced for every burst in the study.

Figure 1a shows the GRB intensity vs. time in 64 ms bins over the time interval used in the current analysis for BATSE trigger no. 907 (1B911016).

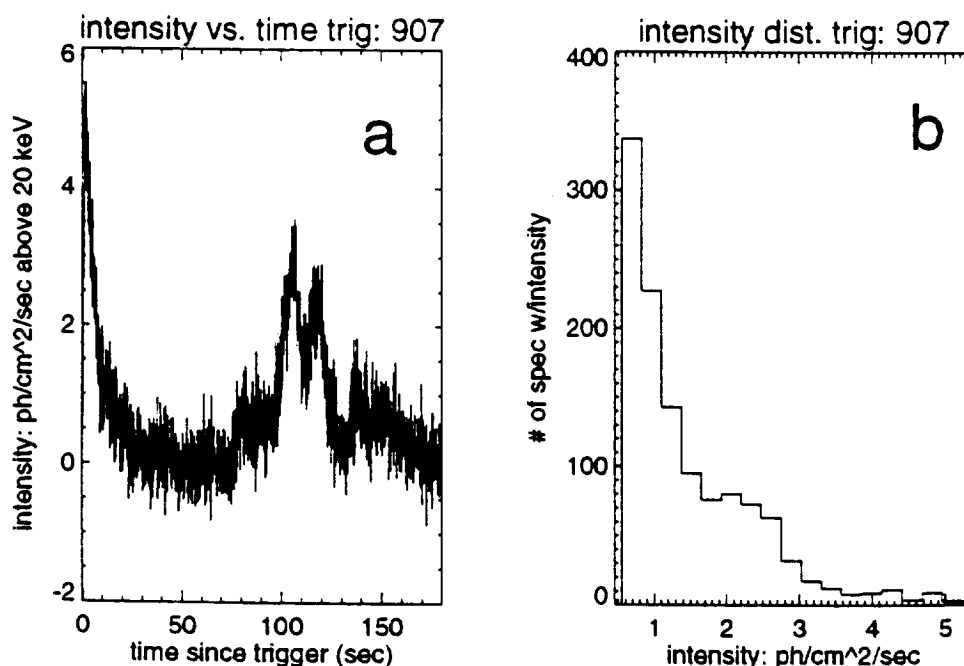


Figure 1. a) The time history of BATSE trigger number 907 (1B911016) in 64 millisecond bins. b) The associated intensity distribution.

The counts per bin here have been multiplied by the inverse of a coarsely binned detector response matrix to yield photons per bin. This analysis gives intensity estimates in each discriminator bin and removes energy dependent effects of detector angular response and atmospheric scattering contamination. It also removes as much as is possible systematic correlations of the intensities between bins caused by higher energy photons registering in lower energy bins due to partial energy deposition in the detector.

The first step in the analysis was to build an intensity distribution of the spectra that comprise each burst. This involved taking the individual 64 ms rates shown on the left in figure 1 and sorting them by intensity into bins to

create an intensity distribution for the burst. This kind of analysis removes any time evolution inherent in a burst but effectively separates the low and high intensity components for study. The effects of the definition of intensity, i.e. the energy range chosen for the flux, were studied by performing the analysis with different definitions of intensity: 20-100 keV, 20-300 KeV, 50-300 KeV.. 100 keV and up., and 20 keV and up. The conclusion that two spectral states are present in many bursts could be drawn from the results with any of these intensity definitions.

The effect of statistical variance on the hardness vs. intensity plots was also studied to insure that the algorithm design did not introduce significant spurious correlations of hardness vs. intensity due to definitions of the intensity range or background subtraction systematics.

Figure 1b shows the intensity distribution of burst 907. The bins have width $1/20$ the peak 64 ms intensity and intensities below $0.45 \text{ photons/cm}^2/\text{sec}$ are discarded. This lower limit is about twice the intensity level at which background subtraction systematics start to distort the results of the analysis as determined from studies mentioned above. Each 64 ms spectrum is placed in the appropriate bin and the resulting distribution shows the number of spectra in each intensity bin. The intensity distribution in figure 1b is an example of the non-uniform behavior observed in many bursts, i.e. there appear either to be two intensities around which most of the spectra cluster or one intensity around which many of the spectra cluster on top of a broader distribution of intensities. Other intensity distributions appear uniform, i.e. there is just one discernable broad distribution of intensities comprising the burst. A distinct jump in the hardness ratio occurs in bursts with non-uniform intensity distributions. Figure 2 shows the average hardness ratios calculated for the first two discriminator channels for all the 64 ms spectra in the associated intensity distribution bins shown in figure 1b. It is possible to calculate the average hardness ratio fairly precisely at the lower intensities since the 64 ms spectra of similar intensity are summed together to improve the total statistical significance. This increase in spectral precision at lower intensities is the primary advantage of the intensity distribution technique. This plot shows that the hardness ratio for trigger 907 remains fairly constant at about .3 below an intensity of $3.0 \text{ photons/cm}^2/\text{sec}$ and then jumps to about .75 above this intensity indicating a change in spectral state.

The presence of two spectral states is also in evidence in our 16 channel spectral data. These spectra are converted from counts to photons using the inverse of a suitably binned detector response matrix. The accuracy of the technique is ascertained by applying it to occultation measurements of the steady Crab flux. Figure 3 shows the average low and high intensity spectra for burst 907. The break point between high and low intensity is the point where the change in slope of the intensity distribution is most positive. The average of all spectra with intensities below the break point is shown as crosses in figure 3. The average high intensity spectrum is plotted as diamonds in the figure. The LAD detectors have been calibrated below 300 keV but the channel to energy conversion above this energy has not yet been optimized. The scatter in the points above this energy is symptomatic of systematic distortions in the channel to energy conversion formula when direct inversion is used.

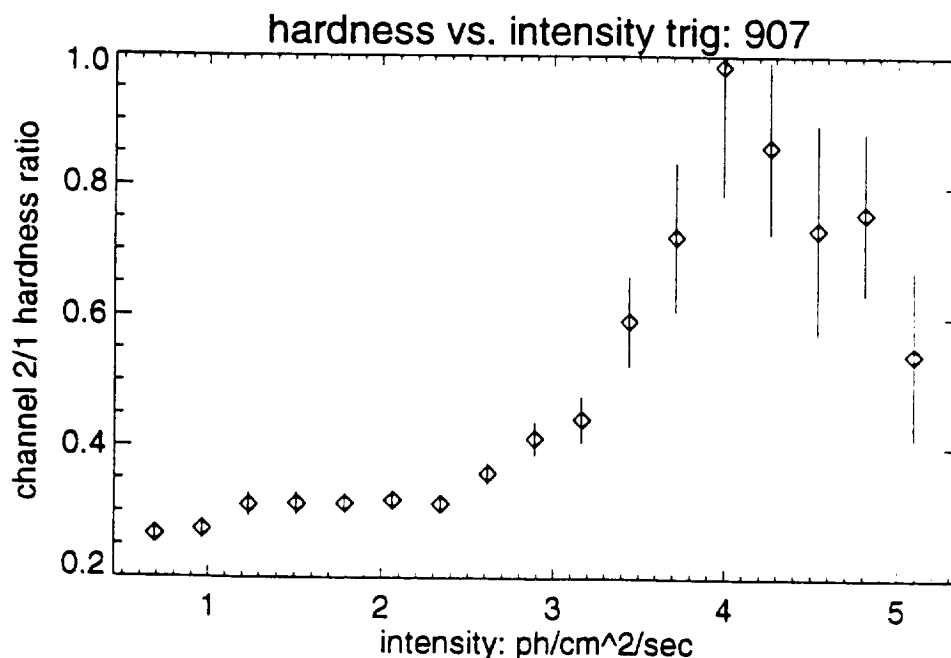


Figure 2. Hardness ratio vs. intensity for BATSE trigger no. 907 (1B911016). The hardness ratio of 50-100 keV flux over 20-50 keV flux is calculated for the average spectrum in each intensity bin of figure 1b.

The low intensity spectrum is consistent with a physical mechanism that produces a spectrum with fairly constant slope. The high intensity spectrum exhibits a marked change of slope at about 60 keV. A qualitative interpretation is that it is a combination of the low intensity spectrum plus some higher energy component with a deficit of emission below 100 keV.

RESULTS

The presence of two components in gamma-ray bursts is consistent with observations by other instruments. The APEX time histories² suggest different temporal and spectral behaviors between the low energy and high energy burst spectra. Spectra with obvious broad high energy components associated with annihilation emission superimposed on a soft thermal continuum have been reported³. The Konus catalog⁴ contains many spectra qualitatively similar to the high intensity spectrum shown in figure 3.

The intensity distribution technique, coupled with the increased sensitivity of the BATSE instrument, will allow for the separation and quantitative spectral analysis of the two spectral components that appear to comprise many bursts. The isolation of two components that appear in a large number of bursts will put constraints on the environment in which the gamma-ray bursts are produced.

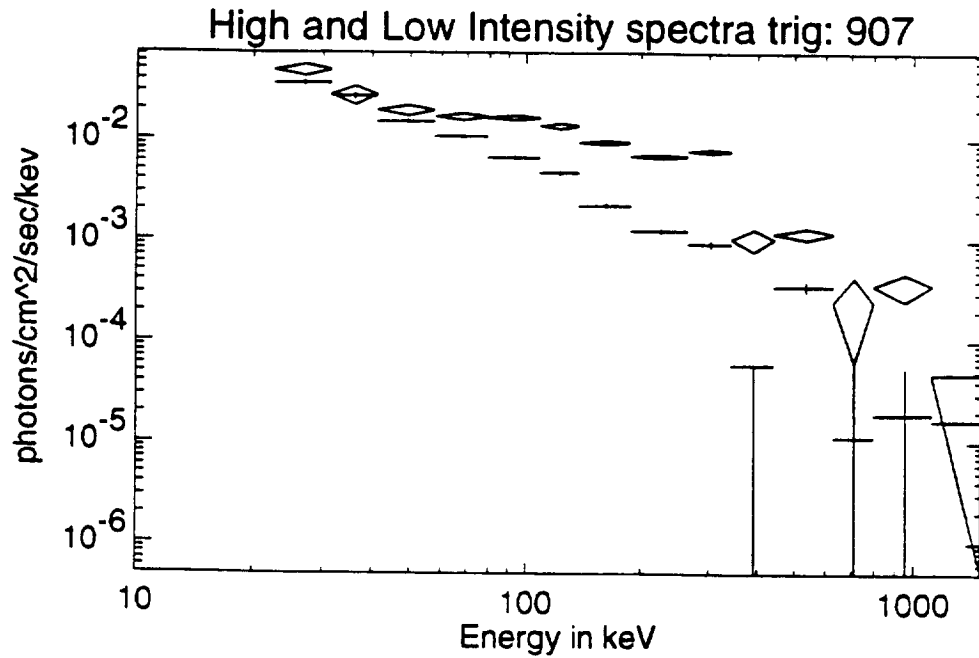


Figure 3. High and low intensity spectra for BATSE trigger no. 907 (1B911016). The high intensity spectrum is represented by diamonds and the low intensity spectrum by crosses. The scatter above 300 keV is due to systematic effects (see text).

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BATSE OBSERVATIONS OF EXO 2030+375

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ABSTRACT

The transient x-ray pulsar EXO 2030+375, first detected by EXOSAT in 1985 May – August, has also been detected by the Large Area Detectors (LAD's) of BATSE. A major outburst occurred during 9 – 19 February 1992. BATSE has also seen this source on six other occasions at intervals of about 46 days. We present the pulse profile, spectrum, period history, and a refined orbital period for this binary pulsar.

INTRODUCTION

EXO 2030+375 was first detected by the EXOSAT satellite from May – August 1985 and again in October 1985¹. Analysis of the data obtained from those viewings indicated EXO 2030+375 was an x-ray transient of the Be binary type with a binary period of 45.6 – 47.5 days and a pulse period of 41.8 sec.² The Burst And Transient Source Experiment (BATSE) aboard the Compton Gamma-Ray Observatory has seen EXO 2030+375 on more than six occasions with, the brightest outbursts being 9 – 19 February 1992 and 25 September – 9 October 1992. We present the first results of our observations.

PULSE PROFILE

BATSE detects many x-ray transients and pulsars using both pulsed and occultation analyses on its Continuous data. Figure 1 shows the pulse profiles of EXO 2030+375 for the two brightest periods seen by BATSE as a function of relative phase from epoch – folding analysis. The pulse phase origin is arbitrary. Two cycles are shown for clarity. In each case, the first profile is summed in energy from 20 – 120 keV, while each succeeding profile is over a smaller energy band. These bands are how BATSE divides up its observable energy range for the current configuration. A double peaked structure is seen in both profiles. By double peak we mean the peaks at 0.4 and 0.7 relative phase. These peaks are more pronounced than those of EXOSAT's³, however, BATSE observes EXO 2030+375 in a higher energy range. BATSE has not detected the variations in pulse profile reported by EXOSAT² primarily due to our inability to observe this pulsar beyond a 14 day range centered about periastron.

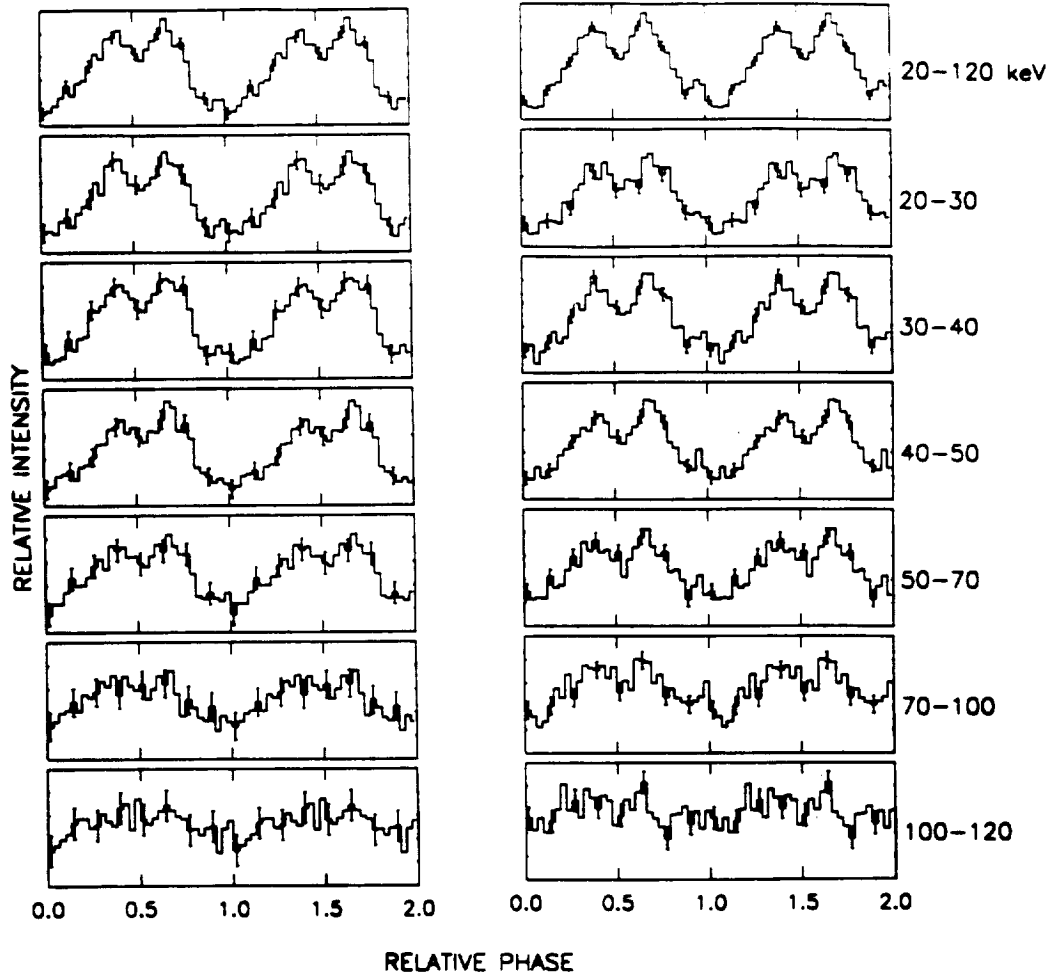


Figure 1. The pulse profile of EXO 2030+375 as seen by BATSE during the 9 – 19 February outburst (left) contrasted with the profile seen by BATSE during the 27 September – 9 October outburst (right). The zero phase point is arbitrary.

PHOTON SPECTRUM

The spectrum shown in figure 2 is from epoch - folded Continuous data for the 9 – 19 February viewing period. A power law fit to the data over the full viewing period gives a spectral index of $\gamma = -3.32 \pm 0.10$. Power law fits to each of the two peaks in the profile (relative phase 0.35 to 0.55 and 0.60 to 0.75) have indices consistent with each other and this result. Background for these spectral fits is obtained from the interval of relative phase 0.80 to 1.25.

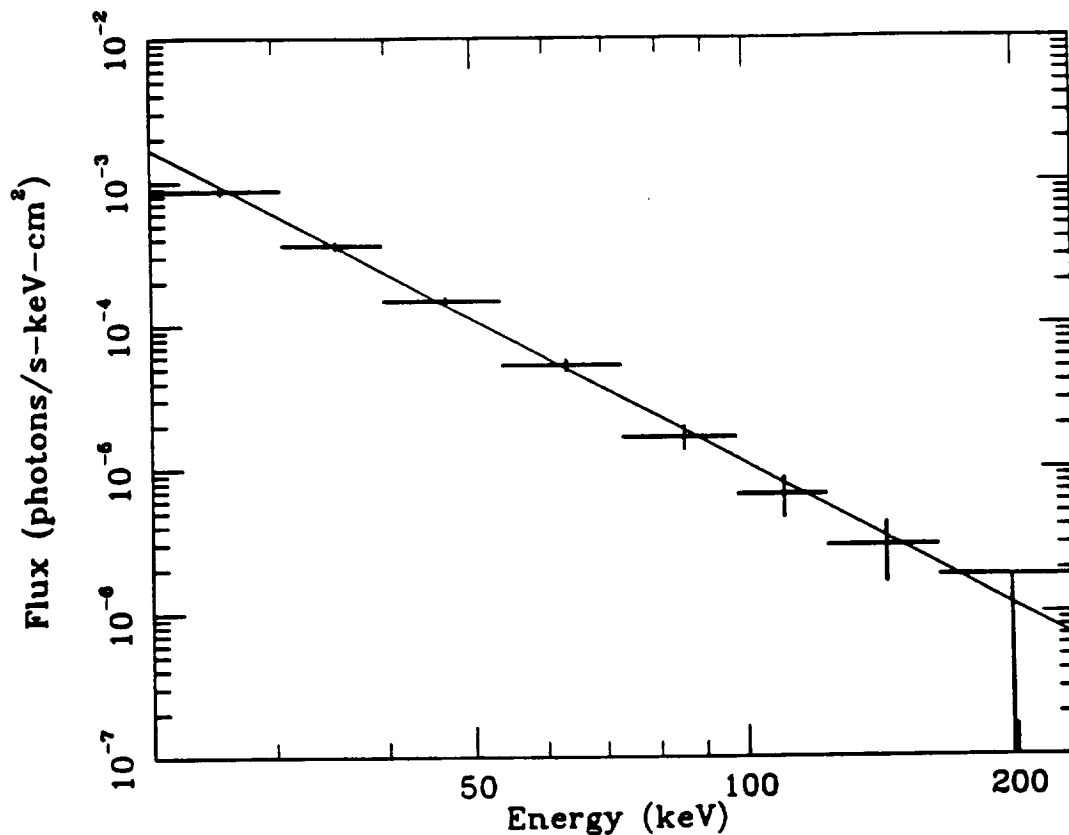


Figure 2. Photon spectra for the 9 - 19 February EXO 2030+375 pulse profile. A power law fit yields a spectral index of $\gamma = -3.32 \pm 0.10$.

Figure 3 shows the photon spectrum for the interval 25 September - 9 October 1992. A power law fit to the data yields a spectral index of $\gamma = -3.24 \pm 0.11$, consistent with the 9 - 19 February index. Inset to this is the photon spectrum produced using occultation data during the entire outburst period. The spectral index $\gamma = -4.19 \pm 1.12$ agrees with that obtained from the pulsed analysis, with reduced statistical significance due to the much shorter livetime available with this technique.

ORBITAL FIT

Figure 4 shows a preliminary orbital fit to the data from the two bright outbursts and one intermediate one. The results of this fit are presented below in Table 1. P_{orb} and the eccentricity are within 1σ of those values presented by EXOSAT.² $a_x \sin(i)$ is 2σ from their lowest value and our ω is 5σ above EXOSAT's highest value. Work is in progress to further refine our orbital parameters.

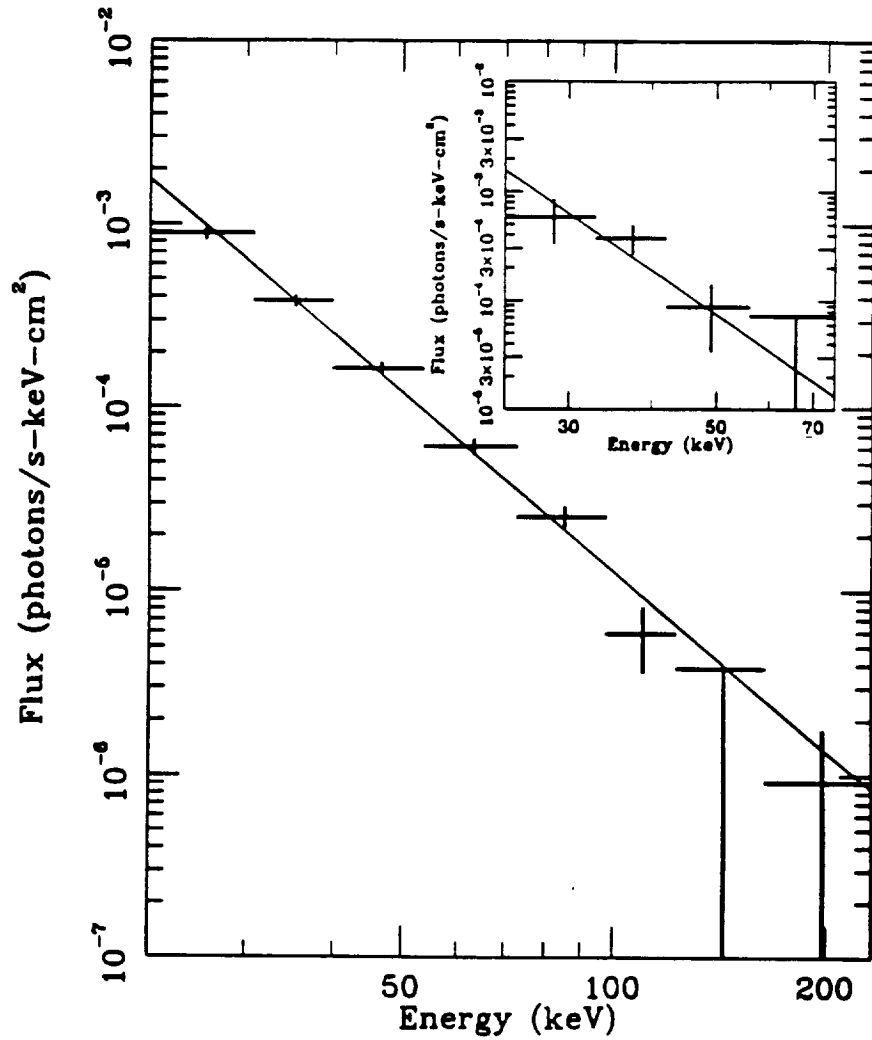


Figure 3. The photon spectrum for 25 September - 3 October. A power law fit gives $\gamma = -3.70 \pm 1.07$ for this data. Inset is the photon spectrum from the occultation analysis, for which $\gamma = -4.19 \pm 1.12$.

Table 1. Exo 2030+375 Parameters	
P_{orb}	46.02 ± 0.01 days
Eccentricity	0.37 ± 0.02
$a_x \sin(i)$	206 ± 12 s
$T_{\pi/2}$	2448781.41 ± 0.03 JD
T_p	$2448800.38 \pm .03$ JD
ω	238 ± 3 deg

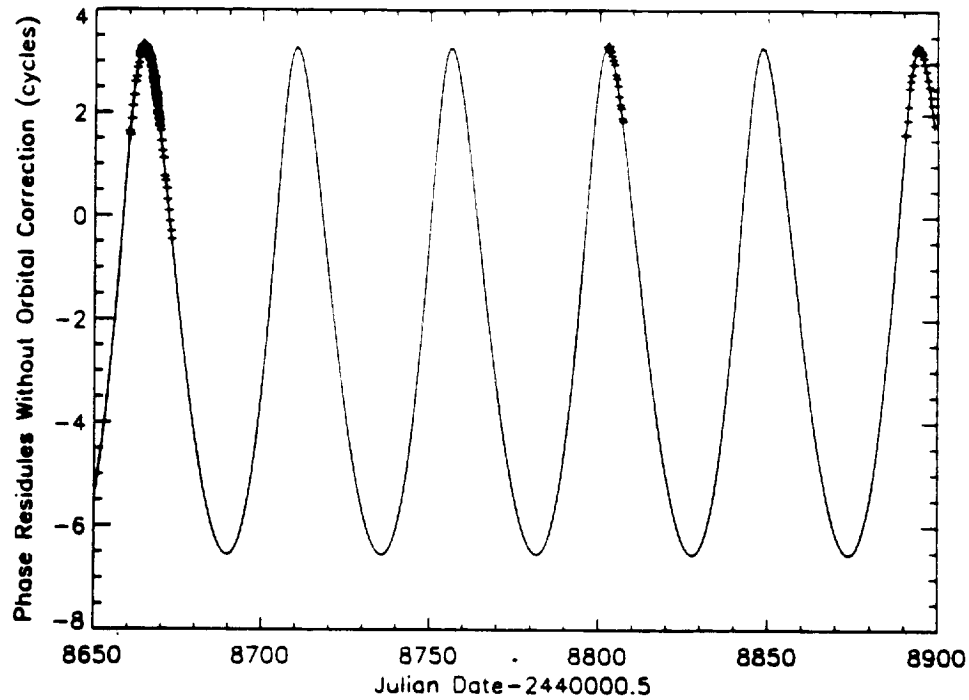


Figure 4. Orbital fit for EXO 2030+375 using BATSE data from 9 – 19 February, 29 June – 9 July, and 25 September – 9 October 1992. Data exists for the three other peaks shown and will be used for a better fit.

REFERENCES

- ¹ Parmar, A. N., Stella, L., Ferri, P., and White, N. E. 1985, IAU Circular No. 4066.
- ² Parmar, A. N., White, N. E., Stella, L., Izzo, C., and Ferri, P. 1989, Ap. J., 338, 359.
- ³ Parmar, A. N., White, N. E., and Stella, L. 1989, Ap. J., 373 - 380.

NASANational Aeronautics and
Space Agency**Report Document Page**

1. Report No.		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle "Data Analysis Tasks BATSE" Final Report				5. Report Due May 5, 1993	
7. Author(s) William S. Paciesas				6. Performing Organization Code University of Alabama in Huntsville	
				8. Performing Organization Report No.	
9. Performing Organization Name and Address University of Alabama in Huntsville Huntsville, Alabama 35899				10. Work Unit No.	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546-001 Marshall Space Flight Center, AL 35812				11. Contract or Grant No. NAS8-38609, D. O. 9	
				13. Type of report and Period covered Final September 30, 1991-February 27, 1993	
14. Sponsoring Agency Code					
15. Supplementary Notes					
16. Abstract Miscellaneous tasks related to the operation of, and analysis of data from, the Burst and Transient Experiment (BATSE) on the Compton Gamma Ray Observatory (CGRO) were performed. The results are summarized and relevant references are included.					
17. Key Words (Suggested by Author(s)) Gamma-ray Astronomy			18. Distribution Statement Unclassified-Unlimited		
19. Security Class. (of this report) Unclassified		20. Security Class. (of this page) Unclassified		21. No. of pages 44	
				22. Price	